

*Application*

*For*

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*Title:*

**Method and Apparatus for Eliminating Dead Zone  
in Phase Locked Loops Using Binary Quantized Phase Detectors**

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# **METHOD AND APPARATUS FOR ELIMINATING DEAD ZONE IN PHASE LOCKED LOOPS USING BINARY QUANTIZED PHASE DETECTORS**

## **BACKGROUND INFORMATION**

### Field of Invention

The invention relates generally to phase locked loops, particularly to the elimination of dead zone for phase locked loops using binary quantized phase detectors.

### Description of Related Art

Clock recovery circuits (CRC) are often used in communication systems and other electronic systems to synchronize a local clock to an external system clock. Currently, a phase locked loop (PLL) is the standard approach to constructing a CRC.

FIG. 1 shows a conventional phase locked loop, including the basic components: a phase and frequency detector denoted 1, a low pass filter (LPF) denoted 3, and a voltage-controlled oscillator (VCO) denoted 5.

The phase and frequency detector 1 compares a reference signal denoted 7 to a feedback signal denoted 11 in order to produce a phase error signal denoted 9. The phase error signal 9 is then filtered through the low pass filter 3 and subsequently input to the VCO 5. The VCO 5 generates a signal 11 with a frequency controlled by the filtered phase error signal. The output 11 is fed back into the phase and frequency detector 1. If the two frequencies for the signals 7 and 11 do not equal, the filtered phase error signal

would cause the VCO 5 to shift to the frequency of the reference signal 7. When the shift is completed, the output of the VCO 5 is used as the synchronized signal.

Several types of phase locked loops have been developed using phase detectors such as Alexander phase detector and Hogge phase detector. Particularly, the Alexander phase detector has been widely adopted due to its ease of implementation.

A CRC measures the clock phase and aligns it to the reference clock to minimize bit-error-rate, and the optimum sampling instant is at the center of the data-eye. FIG. 2 illustrates a data-eye diagram with two data-eyes having centers denoted 17 and 19 and a cross point denoted 13. An Alexander phase detector uses the cross point 13 sample as a reference to locate the data-eye centers.

However, due to duty cycle distortion, the cross point 13 in FIG. 2 is offset from the threshold 0 by a dead zone denoted 15. The duty-cycle distortion causes an Alexander phase detector to wander in the interval denoted 14, searching for the cross point, thereby offsetting the locations of the data-eye centers 17 and 19.

## SUMMARY OF THE INVENTION

The present invention provides the method and apparatus for eliminating dead zone in a phase lock loop using a binary quantized phase detector. The present invention allows a binary quantized phase detector to locate a cross point in a data-eye diagram by gradually shifting a threshold value towards the threshold at which a cross point occurs.

In a first embodiment of the present invention, a binary quantized phase detector first receives a signal sampled in a wandering interval caused by duty-cycle distortion, and compares the value of the signal to a threshold value. The binary result of the comparison is then level shifted and subsequently integrated. The output of the integration is set as the new threshold and the process to locate the cross point restarts with the new threshold.

In a second embodiment of the present invention, the integration step takes place only when the data sequence transitions.

## BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings that are incorporated in and form a part of this specification illustrate embodiments of the invention and together with the description, serve to explain the principles of the invention:

FIG. 1 illustrates a prior art phase locked loop with basic components.

FIG. 2 illustrates a data-eye diagram with duty-cycle distortion.

FIG. 3 illustrates a first embodiment of the present invention that integrates quantized values sampled in the wandering interval.

FIG. 4 illustrates a second embodiment of the present invention including transition detection.

FIG. 5 illustrates the second embodiment of the present invention as implemented in a clock data recovery circuit.

FIG. 6 illustrates a flow diagram for one embodiment of the present invention.

## DETAILED DESCRIPTION

FIG. 3 illustrates a set-threshold circuit **100** used to locate a cross point in a data-eye diagram, comprising: a comparator **37** with two inputs **16** and **39** and an output **22**, an integrator block **4**, and a unit delay block **6**.

The first embodiment shown in FIG. 3 sets 0 as the default starting value for the threshold value **39**. Referring now to FIG. 3 in view of FIG. 2, the phase detector first takes a sample **16** in the wandering interval denoted **14** in FIG. 2 and compares the value of the sample with the threshold value **39**; the comparison returns an output **22** of 0 if the comparison result is FALSE and an output **22** of 1 if the comparison result is TRUE. The binary output **22** is then subtracted by 0.5 to obtain an average output value of 0; the resulting value **24** is integrated in the integrator block denoted **4**.

Moreover, the scale factors such as 0.0001 in FIG. 3 are selected in the integration equation as the amount to shift the threshold value of the phase detector up or down, and the value may vary depending on the desired precision with which the detector uses to locate a cross point in the data-eye diagram.

As an example, the cross point shown in FIG. 2 is offset to approximately an amplitude of 0.09, therefore the average value of transition samples in the wandering interval **14** is a positive value and greater than the default starting threshold 0.

Moreover, the output of the integrator block **4** is delayed one cycle in a delay block **6** and then used as the new threshold input **39** for the next comparison in the comparator **37**, and the process to locate the cross point restarts with the new threshold **39**. For the example shown in FIG. 2, the phase detector searches for the cross point at incrementally higher amplitudes with each new threshold value **39**. The increment or decrement amount depends on the scale factor in the integration equation, which is set as 0.0001 for the embodiment shown in FIG. 3.

FIG. 4 illustrates a set-threshold circuit **200** as a second embodiment of the present invention, comprising: a comparator **37** with two inputs **16** and **39** and an output **22**, a XOR function block **8** with two inputs **18** and **20**, a multiplication block **10**, an integrator block **4**, and a unit delay block **6**.

In addition to the integration and shifting to find a cross point in a data-eye diagram, the second embodiment performs the integration step only when data transitions are present in order to eliminate threshold drift during long periods of data sequences without transitions.

The values **18** and **20** are binary results of comparing 0 to sample values taken at data-eye centers, with respect to the location of the wandering interval sample **16**. If the values **18** and **20** differ, indicating a transition in the data-eye diagram, the multiplier **10** multiplies 1 with the quantized value **24**, allowing the integration to proceed. Conversely, if the values **18** and **20** are equal, indicating a data sequence without

transitions, the multiplier **10** multiplies 0 with the quantized value **24** and effectively eliminates the integration step.

Furthermore, since the samples **18** and **20** are located with reference to the location at which sample **16** is taken, the accuracy of the locations for the samples **18** and **20** is improved as the phase detector gradually shifts the amplitude at which it samples **16** towards the desired cross point.

FIG. 5 shows the second embodiment of the present invention implemented as part of an Alexander phase detector based clock data recovery circuit. The clock data recovery circuit in FIG. 5 comprises the basic elements of a PLL, including: an Alexander phase detector denoted **64**, a filter denoted **62**, and a VCO denoted **61**.

As shown in FIG. 5, data inputs are received at block **21**. The sample taken at the center of a first eye is first received in the circuit, and subsequently compared to 0 as illustrated by blocks **49** and **51**. The resulting signal **20**, whose value is either 0 or 1, is delayed one cycle and then released at the output of block **53** as signal **18**.

Referring to FIG. 5 in view of FIG. 2, a sample **16** is taken in the wandering interval **14**, and the sample value is compared to a threshold input **39** whose initial value is set as 0. The resulting signal **22** of the comparison, whose value is either 0 or 1, is the output of the comparator block **37**.



As the sample signal **16** is processed, a third sample taken at the center of a second eye is received in the circuit, and subsequently compared to 0 as illustrated by blocks **49** and **51**. The resulting signal **20**, whose value is either 0 or 1, is the output of the block **51**. Subsequently, the signals **22**, **18**, and **20** are inputs to the circuit **41**, whose components are explicitly illustrated in FIG. 4.

As shown by blocks **41** and **37**, the output **39** of the circuit **200** is the new threshold input for comparison with the wandering interval sample **16**. Moreover, the comparison process continues with all three sample-points as the phase detector adjusts the sampling threshold through the integration performed in the circuit **41**. Since the wandering interval sample **16** is used as a reference to locate the data-eye centers **18** and **20**, as the phase detector adjusts the sampling amplitude to locate the cross point, it consequently adjusts the locations at which the samples **18** and **20** are taken and effectively allows the phase detector to self-center.

FIG. 6 is a flow diagram illustrating the steps for the one embodiment of the present invention. Step **63** shows that a signal **B** in the wandering interval is sampled and compared to a threshold value. If the value of **B** is less than the threshold value, **B** is set to  $-0.5$ ; if the value of **B** is greater than or equal to the threshold value, **B** is set to  $0.5$ , as shown in FIG. 4.

A delay is then inserted to retune the Alexander phase detector in step **71**. While the signal **B** is processed, two other signals **A** and **C** are sampled in steps **75** and **77** at the center of the eyes before and after **B**, using **B** as a reference mid-point location.

Both samples **A** and **C** are subsequently compared to 0 in steps **79** and **81**. If the value of either signal is less than 0, the signal is set to 0; otherwise, the signal is set to 1. Step **91** then applied a XOR function to the resulting signals **A** and **C** to determine if a data transition has occurred in the interval between the two sample points.

Step **91** shows that a temporary variable **T** holds the result of the XOR function; if a transition exists in the data sequence, **T** equals 1; else **T** equals 0. **T** is then multiplied with the value of **B** in step **73** to determine whether integrating the value of **B** is necessary.

If the output **O** of step **73** is 0, the integrating step is overlooked, and the phase detector restarts the sampling process for all three signals. If the output **O** of step **73** is 1, the value of **B** is integrated in step **93**, and the result is set as the new threshold for the phase detector.

Although the invention has been described in connection with several embodiments, it is understood that this invention is not limited to the embodiments disclosed, but is capable of various modifications that would be apparent to a person skilled in the art.

For example, the Alexander phase detector and the XOR function shown in the figures are intended as illustrations, other binary quantized phase detectors and means to determine if two values are equal may be used in conjunction with the present invention without departing from the spirits of the present invention. Moreover, the multiplication block 10 in FIG. 4 may be replaced with other means such as a table look up or a gain stage, to filter out the wandering interval sample.

It is understood that common practice such as representing binary values with "0" and "1" or TRUE and FALSE may be implemented by various means without departing from the desired representation.

Temporary variables shown in FIG. 6 such as **T** and **O** are used to clarify the details of the embodiment and may not be necessary in actual implementation.

Furthermore, constants such as 0.5 used in FIG. 2 and FIG. 3 to level shift the input signal so that its mean value is zero, may be replaced by other constants, the comparisons may substitute its operators such as  $\geq$  to  $>$ , the default threshold value 0 for block 39 may be altered, and the scale factor for the integrator may be adjusted to desired precision requirements without altering the essence of the present invention.

The foregoing descriptions of specific embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be

exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, to thereby enable others skilled in the arts to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the Claims appended hereto and their equivalents.